EXECUTIVE SUMMARY

The widespread degradation and loss of the main reef-building corals, elkhorn coral and staghorn coral, on coral reefs throughout the Caribbean was the focus of a three-day workshop held at the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS). The workshop was sponsored by the National Oceanic and Atmospheric Administration (NOAA Fisheries) to obtain status reports about the distribution and abundance of these corals in Florida, Puerto Rico, the U.S. Virgin Islands, and the wider Caribbean. Workshop participants included coral reef biologists, ecologists and geologists, resource managers and policy experts from the U.S. and Caribbean, with representation by Federal, State, Territorial governments, universities and non-government organizations.

Elkhorn and staghorn corals are the two major reef building corals in Florida and throughout the Caribbean that once formed dense thickets at shallow and intermediate depths, contributing significantly to reef growth, island formation, coastal protection, fisheries habitat and biodiversity. Their decline has changed many coral reefs from spectacular three-dimensional living structures to flat "parking lot" stretches of seascape. Reports heard at the workshop added to the building body of evidence that elkhorn and staghorn corals have declined significantly in abundance from their historical levels and throughout their range across the Caribbean region. Disease outbreaks were identified as a major cause of coral loss, but habitat degradation, storm damage, coral bleaching, outbreaks of predators, competition by encrusting and bioeroding organisms, physical damage from anchoring and ship groundings, and other human impacts have also killed large amounts of coral. As recently as the 1980s these corals were a common feature of many reef environments, where they formed dense thickets and extensive stands of healthy, fast-growing coral. The loss of these species will result in a major loss of reef function and structure and may contribute to accelerated coastal erosion.

Elkhorn (*Acropora palmata*) and staghorn (*Acropora cervicornis*) corals were added to the Candidate Species List of the Endangered Species Act (ESA) in 1999 by NOAA's National Marine Fisheries Service (NMFS)[1]. The main intent of the workshop was to gather additional information on the status of these corals, evaluate how effective existing measures are at protecting these species, and propose additional conservation strategies that need to be implemented to restore these species. Four working groups were established and charged with evaluating the: 1) status and trends of elkhorn and staghorn coral populations and threats affecting surviving corals; 2) biology and ecology of the species as it affects future trends and potential rebuilding of the species; 3) management options to conserve the species; and 4) information needs to aid in their conservation. In addition to the specific recommendations developed by the working groups, all participants agreed that a major, well-organized effort is needed to systematically identify the causes of the decline, pull together what's been done, and determine exactly what needs to be done to halt the loss of these species; improve the ecological and physical conditions of these reefs so they can once again support elkhorn coral and staghorn coral populations; and develop strategies to promote coral recruitment and restore degraded coral populations.

The workshop participants concluded that recent information is available on their status from 60-75% of all reefs where these species occur. Both species still occupy their historic range, although localized range reductions and extirpations have occurred. Most populations have experienced losses of 80-98% of their 1970s baseline, although healthy stands are still found in a few locations and limited recovery through sexual

[1]*Acropora prolifera* is mentioned in several reports and abstracts throughout these proceedings, but it was not listed as a candidate species for the ESA and was not considered a separate species during this workshop. Vollmer and Palumbi (2002) present data that demonstrate that *A. prolifera* is a morphologically variable, first generation hybrid of *A. palmata* and *A. cervicornis*.

recruitment and/or regrowth of fragments has been observed. Over the last year *A. palmata* populations in a number of locations have been stable, although at only 5% of their historical abundance. There are numerous sites where additional populations are highly vulnerable to extirpations over the next 5-20 years. On a regional scale, there have been few signs of recovery since the initial decline. However, through the development and implementation of management actions that alleviate or minimize the threats impacting these species, there is a high potential for recovery.

Caribbean Acroporids have several unique life history strategies that can allow colonies to persist and recover under the right environmental conditions. Although they exhibit infrequent or sporadic sexual recruitment, these species can rapidly recolonize an area through a process known as fragmentation. A certain frequency and intensity of storms is thought to be important in maintaining and rebuilding local populations by breaking and dispersing branches, which can reattach and regrow. However, in many locations, populations have been reduced to such an extent that the potential for recovery through regrowth of fragments is limited and recovery is dependent on recruitment of sexually-produced larvae. Unfortunately, fertilization success may also decline as these and other sessile benthic broadcast spawners are likely to exhibit density dependent reproduction. In addition, genetic variability of remaining colonies may be drastically reduced which can have positive short- term (locally-adapted disturbance resistance populations) but negative long-term (ie. genetic introgression) implications.

Although participants felt there was sufficient information available on the status and trends of these species and the threats they face to make a decision whether an ESA listing is justified, they identified numerous information gaps. Key research needs include studies on 1) the biology of these species, with an emphasis on reproduction; 2) geologic time scales and linkages among past die-offs and the recent decline with respect to the importance of natural versus anthropogenic disturbances; 3) etiology and epizootiology of coral diseases; 4) genetic studies including linkages among populations, genetic exchange between populations, and effect of disturbance on genetic diversity; 5) scientific information on demographic parameters and habitat-based variables; and 6) evaluation of strategies to enhance recovery, including propagation and transplantation into degraded areas and techniques to mitigate threats. One of the key needs that is currently lacking is a model for modular (colonial) organisms capable of providing a reliable method to predict the current risk these species face and potential for this to continue into the future. Emphasis needs to be placed on the development of a model that incorporates demographic parameters, life history traits, and threats.

The overall conclusion of all participants of the workshop was that 1) both *Acropora palmata* and *A. cervicornis* have been severely reduced throughout their range; 2) these species have many mechanisms for recovering from physical damage including the development of new colonies from fragments; 3) there is limited recovery occurring in some areas through both sexual and asexual recruitment; but 4) it is not clear that these species will be successful at recovering to their former extent without specific management interventions, given the current assault from the overall, unprecedented combination of stresses, including biotic factors (predation and disease), mass bleaching events, physical damage from hurricanes, anchorings, and ship groundings, and degraded water quality. These corals are critical components of Caribbean coral reef ecosystems and both the structural and ecological roles of *Acropora* spp. are unique and cannot be filled by other species. Therefore it is essential that management initiatives are undertaken to address the threats affecting these corals, protect remaining populations, and rebuild and recover degraded populations. Conservation efforts are likely to be most effective when each coral population is considered independently, and any conservation action takes into account the preservation of a high genetic diversity. *Acropora palmata* and *A. cervicornis* could benefit from the protection the ESA affords and the listing will provide valuable added protection for many other reef species dependent on them.

Summary of Resolutions from the Biology and Ecology Working Group

1. The structural and ecological roles of Acroporid corals in the Caribbean are unique and can not be filled by other coral species. Their rapid accretion rates and structural complexity are unmatched. The loss of these characterstics will likely result in a significant loss of reef function and structure. At present, there is no indication that any other Caribbean coral species can replace the important role that Acroporid corals play within reef communities of the region.

2. Two sources of disturbance, diseases and storms, were identified as the main contributors to the regional decline of *Acropora* spp. In addition, sources of mortality such as chemical pollution and space competition from excavating sponges, were identified as "emerging issues" where more research is needed to fully predict their impacts.

3. White-band disease, which affects both *Acropora palmata* and *A. cervicornis*, is believed to have been the principal cause of mortality in these species throughout the Caribbean region in the past two decades.

4. Acroporid corals may require a certain storm frequency to be able maintain and expand populations through asexual recruitment when sexual recruitment is limited. However, a frequent occurrence of storms or a particularly intense hurricane may impact colony and fragment survival.

5. For Acroporid corals, which exhibit reportedly sporadic or limited sexual recruitment, asexual reproduction can play a major role in maintaining local populations. However, as population abundance decreases or disturbance patterns increase to the point where remaining coral populations are no longer able to survive and propagate by asexual means, the relative importance of sexual reproduction and recruitment increases. Anecdotal evidence and observations made by reef researchers at several locations throughout the region indicate that both *A. palmata* and *A. cervicornis* do indeed recruit sexually onto reefs and that in several instances populations that have experienced major declines (< 90%) are presently showing signs of recovery from newly settled sexual recruits.

6. The information available on patterns of asexual propagation has shown that, under the right environmental conditions, fragmentation followed by fragment stabilization, survivorship, and regrowth can provide an efficient mechanism for maintaining and expanding Acroporid populations. However, while fragmentation followed by fragment stabilization and growth may have been sufficient to maintain and expand Acroporid populations in the past, recent patterns of regional decline have increased the reliance of these species on sexual recruitment as a means of establishing and sustaining populations. Accordingly, the regional recovery of Acroporid populations will depend largely on the future success of sexual recruitment.

7. The scientific capability to assess the potential for recovery of *Acropora* spp. populations by sexual propagation of surviving populations is seriously impaired at present by the general lack of knowledge of the different aspects of this process. This was identified as a key research area where efforts need to be allocated in the future to determine: 1) spatial and temporal patterns of gamete formation and release; 2) size-stage thresholds for gamete production; 3) within and among colony variability in gamete production; 4) fertilization patterns; 5) transport and duration of larval stages; 6) larval survivorship patterns; 7) settlement requirements and preferences of coral planulae; and 8) early survivorship and growth of sexual recruits.

8. In light of the recent drastic decline of these critical structural (foundation[1]) species, it is important that we understand the influence of disturbances on the genetic composition and genetic variability within and among Acroporid populations. Furthermore, faced with the uncertainty about their recovery and long-term status, it is important to determine whether these disturbances have modified underlying genetic variability, favoring locally adapted, disturbance-resistant populations. This information will be crucial to: 1) evaluate, based on present genetic structure, the potential impact of future disturbances, and 2) determine, based on prior genetic exchange, the recovery capability of local populations from remaining regional sources of propagules. Similarly, information on the clonal structure of the populations will aid in the decision making process on marine reserves and management plans by identifying specific locations and populations at risk based on factors such as genetic isolation and genetic structure.

9. The preliminary results highlighted here can have important conservation implications – namely, each coral population should be considered individually and any conservation strategy (esp. transplantation studies) should take into account preserving 'meaningful genetic diversity'.

Summary of Resolutions from the Status and Trends Working Group

1. Once dominant species on shallow reefs (0-15 m depth) throughout the greater Caribbean, Acroporid abundance has been drastically reduced in abundance and spatial dispersion. In many areas, previously densely populated subpopulations (or monospecific thickets) now consist of no or few individuals. Present and future likelihood of disturbance to their abundance and habitat remains high due to both natural and anthropogenic factors.

2. The status of Acroporids has changed significantly since the 1970s with a region wide decline occurring in the 1980s and subsequent localized declines during the 1990s. The 1970s represents a baseline for "stable, healthy" populations and the 1980s as a baseline of the regional decline primarily resulting from white-band disease. Additional shifting baselines are useful to understand local and current declines; for example, regional mortality from disease is compounded on a local scale by hurricanes, bleaching events, and outbreaks of predators.

3. *Acropora palmata* and *A. cervicornis* have experienced an unprecedented decline throughout their historic range since the 1980s, including both a significant reduction (loss of 80-98%) in the number of individuals and an extreme reduction in area of distribution. Neither species have recovered to their former abundance. Some local *A. palmata* populations have been stable over the last year with evidence of recovery and limited sexual recruitment (e.g., USVI). *Acropora cervicornis* experienced a more severe decline with no or few signs of recovery or sexual recruitment (except Broward County, FL). Acroporids have a high likelihood of localized extirpation and possible extinction on ecological time scales (10-100 yrs).

4. White-band disease (WBD) is believed to be the primary cause for the region wide Acroporid decline during the 1980s. Current factors causing mortality or stress are highly localized, with some areas showing greater susceptibility to disease (e.g., Florida Keys, Belize), predation (e.g., Florida Keys and Puerto Rico), and storms (e.g., US Virgin Islands). Given the declined state of Acroporids and the increase in the frequency and intensity of disturbances, these sensitive species are highly vulnerable to both natural and anthropogenic stressors, especially synergistic disturbances.

5. An estimated 60-75% of the entire Acroporid population has been examined and enough information is available to make a determination whether these species are threatened or endangered. Approximately 5%, and no more than 10% of the population resides within US waters. Several geographical areas where more information is needed include Bahamas (especially southern), Nicaragua, Pedro Banks, northern Cuba, Haiti, Banks off of Turks and Caicos, Saba Banks, eastern Caribbean, and Trinidad and Tobago.

6. The historic range of Acroporids is believed to be the same as the current range, although it is not possible to conclude with certainty given the current scientific inability to differentiate genetically distinct populations. Local range reductions and extirpations have occurred and it is believed some populations may be reproductively isolated. Given the extent of decline and vulnerability to extirpation, it is believed these corals remain threatened throughout their range.

7. To assist in the recovery of these species, more scientific information is needed on both demographic variables as well as habitat-based variables including 1) survival and fecundity by age and frequency distribution of ages (size or stage structure[2]); 2) reliance of populations on asexual vs sexual recruitment; 3) genetically distinct populations, minimum population sizes, and amount of genetic exchange between populations; 4) juvenile population dynamics (e.g., survivorship, growth rates); 5) importance of habitat variables to recruitment and adult survivorship (e.g., standing dead colonies, vertical relief, habitat condition, cross shelf position); and 6) location of "endmember" populations and those showing signs of recovery and/or sexual recruitment.

8. *Acropora palmata* and *A. cervicornis* warrant further listing under the Endangered Species Act (ESA) and could benefit from the protection the ESA affords. Acroporids are likely to qualify for listing as threatened or endangered species because of the significant reduction in their abundance and high likelihood for future population declines; the current loss of habitat and potential for future loss of range remains high; they are highly susceptible to severe population reductions due to disease and predation; there are few existing regulatory mechanisms to minimize further reductions or impacts; and both natural and anthropogenic factors are likely to affect their continued existence. The likelihood of extinction for both species could be reduced by alleviating threats and implementing strategies that promote their recovery. The listing of these species will provide valuable added protection to both corals, as well as the many other species dependent on them.

[1]Species of large effect fall into two general categories: 1) structural or foundation species, which provide most of the three-dimensional architecture in which other species find shelter and food; 2) keystone species, which by virtue of their high rates of consumption and their generalized diets, exercise disproportionate control over the distributions, population sizes, activities, and adaptive characteristics of many other species (Vermeij, 2001). Based on this definition, the workshop participants determined that *Acropora palmata* and *A. cervicornis* are (1) structural or foundation species.

[2]Stage structure refers to a particular life history stage of *Acropora* spp., including a sexual recruit, fragment and whole colony.

Summary of Resolutions from the Management Working Group

1. The existing regulatory framework in the U.S. and its territories, as well as in many Caribbean nations offers limited protection to Acroporid populations through 1) the establishment of parks, sanctuaries and reserves; 2) fishery management plans that limit or prohibit the take of corals; restrict the use of fishing gears that cause habitat damage and breakage of corals, especially no-take reserves; 3) federal, state and territorial programs to establish and maintain mooring buoys to minimize coral breakage associated with anchoring; and 4) coastal zone management strategies that address shoreline development, sewage treatment and discharge, and destruction of associated habitats such as mangroves. However, the existing regulatory structure is insufficient for most *Acropora* populations; additional measures are necessary to improve water quality, address coastal development, improve navigational aids, address habitat damage from anchoring, destructive fishing gears, and boat groundings, and enhance enforcement.

2. A variety of protected areas exist in Florida, USVI and Puerto Rico, including National Monuments, Sanctuaries, Reserves, and Wildlife Refuges. These and other areas are typically zoned for specific or multiple uses, often include no-take areas, and offer various protective measures such as a prohibition on extractive activities. However, in general, they encompass a relatively small portion of the total *Acropora* habitat, they offer limited protection from various environmental impacts such as water quality issues, and enforcement may be limited or lacking.

3. Over the last five years Florida, USVI, and Puerto Rico have made major conservation advances through the establishment of various types of marine reserves and proposals for new marine protected areas. Many of these have been established in coordination with initiatives to address habitat destruction through fishing gear regulations, installation of mooring buoys and navigational aids, no anchoring zones, improved wastewater treatment, and other measures.

4. Coral reefs and associated habitats provide fishery resources that represent a critical source of food, but increased rates of collection and associated habitat destruction are threatening the regenerative capacity of of these species and critical linkages among species, and in some cases are contributing to phase shifts. A number of management initiatives have been proposed including improved monitoring and protection for fishery resources; greater habitat protection through establishment of no-take MPAs and other efforts; measures to protect spawning populations; elimination of destructive fishing practices and gears; implementation of gear restrictions; and incorporation of ecosystem-scale considerations in Fishery Management Plans.

5. Coral diseases and coral predators need far more study. Managers need to know the causes of diseases affecting Acroporids, how diseases are transmitted, and any actions that can be taken to reduce their negative impacts on *Acropora* populations. Efforts should be made to determine the degree of disease resistance that exists among clones, and genetic mechanisms for resistance. Research is also needed to determine the efficacy of programs to control potential "pest" species such as *Coralliophila abbreviata* and *Stegastes planifrons*.

6. Pollution and sedimentation could be signficantly reduced by fully implementing existing authorities among various federal, state and territorial agencies, but this will require greater efforts to monitor existing water quality, expanded studies to determine the ecological relevance of various pollutants, and improved permitting mechanisms for development projects that affect coral reefs. Local partnerships among governments, land owners, industry and the public are necessary to implement measures to reduce land-based runoff and prevent discharge from known point sources.

7. Coral mariculture, aquaculture and other propagation techniques, along with transplantation, and reattachment of dislodged *Acropora* fragments may provide a feasible strategy to rebuild degraded *Acropora* populations. These efforts may be especially useful in areas for which natural recovery is unlikely (due to an absence of parent colonies or sexual recruits), and on a small scale to speed up recovery following a ship grounding. However, care must be taken to ensure that source coral populations are not degraded, genetic diversity is maintained, and potential introductions of pathogens or other invasives are avoided. In addition, restoration efforts should not be undertaken unless the source of the threat has been identified and addressed. Because we know very little about appropriate restoration strategies and potential long-term benefits, all restoration efforts should be undertaken using an experimental approach that includes measures to evaluate success.

8. A number of countries have taken key steps to protect coral reef ecosystems within their waters through the development of MPAs, implementation of Fishery Management Plans, and development of strategies to address water quality issues. However, these efforts need to be greatly expanded on a local to regional scale and substantial new initiatives are necessary. There is a need for improved sharing of information and technical assistance from the U.S.; greater efforts to educate the public and user groups regarding the importance of coral reef ecosystems, threats, and solutions; and better cooperation among different government agencies, non-government organizations, industry and the public.

9. Several regional and international fora, including CaMPAM, SPAW, ICRI, GCRMN, CITES, AGRRA and CARICOMP are available to assist in the regional and international protection of Acroporid corals through improved management, monitoring, and conservation. However, there are various limitations with these initiatives, such as funding and leadership problems, a capability to adopt measures that address important concerns but not necessarily the most critical concerns for these species, and limited public, government and/or industry support.

10. An ESA listing would provide additional necessary conservation mechanisms, above and beyond the existing tools available to resource managers. The listing could protect and restore these species while providing added benefits for associated species; it would provide for increased recognition and awareness of coral reefs, their importance and their vulnerable condition; and it would enhance our ability to fill information gaps through support for targeted research and monitoring. An ESA listing would also add additional burdens and costs for increased management, enforcement and permitting of activities. No single mechanism is likely to be sufficient to halt the decline of these corals and enhance their recovery. It is likely that managers will have to apply all of their tools to ensure recovery of these species, including application of the ESA.

Summary of Resolutions from the Information Needs Working Group

1. There is a need to compile existing maps, historical and current aerial photographs, bathymetric information, airborne sensor data and other types of information showing existing and potential *Acropora* habitats and associated terrestrial and marine habitats essential to the conservation of Acroporids. These data should be incorporated into a GIS database to delineate critical habitat and design appropriate conservation strategies to protect these areas. While a good deal of recent information is available from U.S. locations, there is a need for ground truthing of maps and improved resolution of maps, as well as a need for expanded mapping efforts in non-U.S. locations.

2. While sensor-based reef mapping technologies can provide high resolution information on the distribution of ecological communities, current technology does not provide a reliable tool to distinguish among species of corals or condition (live, dead or diseased or bleached colonies). Thus, the use of sensor-based mapping tools must be combined with underwater visual, video and photographic monitoring and assessment.

3. There is a need for larger, regional scale coring programs to compile a long-term record and compare this to present day changes.

4. We need to improve our understanding of the nature of recent regional declines in *Acropora* populations, and whether evidence for causes of past declines are preserved in the geochemistry of *Acropora* fossils, to determine whether the observed decline is part of a natural cyclical process for which natural recovery is likely, or whether anthropogenic stressors have exacerbated these processes and may inhibit recovery.

5. Reef restoration at any scale will have, at best, very limited success unless the causes of decline are understood and action is taken to reduce these threats.

6. Transplantation and propagation of *Acropora* colonies are viable tools to enhance recovery at local scales, but considerations such as appropriate selection of colonies and fragments, the potential effects on genetic structure of populations, and the potential benefits must be weighed against the probability of natural recovery, other management interventions, and likelihood of long-term success.

7. Efforts to enhance sexual recruitment may provide a useful tool to promote recovery of populations, but additional research is needed to understand different aspects of sexual reproduction, including basic information on reproductive biology, role of water circulation in transport of larvae, and larval settlement requirements.

8. Novel ecological restoration efforts, such as strategies to enhance herbivory, reduce predation pressure, eliminate pest species, and mitigate diseases may have benefits on a local scale, but it is critical that these efforts be undertaken using a science-based approach that incorporates efforts to understand ecological processes and potential impacts of human modification of these processes.

9. Greater efforts are needed to monitor and assess *Acropora* populations at local to regional scales, at time intervals appropriate to the process under investigation, including studies to follow individual colonies at various life stages exposed to different environmental conditions and anthropogenic stressors.